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REPORT ON ELECTRICAL CHARACTERISTICS OF AN AIR-SOURCE HEAT PUMP[1]

by

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Introduction

As summer air-conditioning equipment has been improved in design and operating efficiency, it has been installed in increasing numbers of rural homes. The addition of this new electric load may be coupled with a high power demand during seasonal farm work. Annual electrical peak loads in summer first appeared on service systems in the South and gradually moved northward. At the same time, the margin of difference between summer and winter loads has become progressively larger.

How does installation of a heat pump fit into the picture of an imbalance between summer and winter loads? A study of the demand of the heat pump, it was realized, would provide information to evaluate it as a year-round load balancer. In this connection, peak power demands and the annual load factor of heat pumps are of particular concern to the power supplier. Operation of the heat pump, which supplies summer cooling as well as winter heating, was therefore recorded, in tests at Beltsville, Md.

One result of the more efficient use of electric generation and transmission capacity could be a lower rate for electric energy. Hence, the use of the heat pump would benefit the prospective buyer as well as the power supplier. This is particularly significant on those farms where the conventional house-heating fuels are unavailable or are available at a price higher than in urban areas.

1/ The work reported herein is the result of cooperative research.

The authors gratefully acknowledge the aid and assistance of G. R. Mowry and J. G. Hartsock of the Farm Electrification Research Branch and A. A. Biggs and H. J. Thompson of the Livestock Engineering and Farm Structures Research Branch of AERD, ARS, USDA.

There are other advantages that are, perhaps, of greater significance and interest to the houseowner. Year-round automatic temperature control in a single compact and all-electric system requires a minimum of personal attention and provides maximum convenience. Cleanliness of operation, uniform humidity, and controlled filtering and circulation of air--components of comfort air conditioning--may be largely achieved with the heat pump.

The ability of the heat pump to reclaim heat from sources such as air or water through provision of mechanical work, has further significance from the standpoint of conservation of resources. For each unit of heat energy provided to the motor, one to two additional units are garnered from water or air to provide a total of two or three heat units for heating the farmhouse.

This report concerns the use of a commercially available domestic-type heat pump installed at Beltsville, Md., in an experimental farmhouse at the USDA Agricultural Research Center.

Farmhouse Description

The farm residence (Fig. 1 and 1-B) was a single-story, one-bedroom farmhouse with a floor area of 770 square feet. The house was of low thermal-mass construction of aluminum roofing and siding. Roof insulation was 2-inch tongue-and-groove roof plank. Wall insulation made use of the air space principle utilizing aluminum construction (Fig. 1-A). The overall heat factor,[2/] a measure of the degree of effectiveness of the house insulation, was determined to be 0.38.

The house had no storm windows or storm doors. Tests were conducted for nearly 2 years without occupants and an additional 2 years while the house was occupied.

Design calculations[3/] for house heating and cooling using standardized methods, were 40,000 B.t.u./hr. at 15° F. outdoor design temperature and 32,000 B.t.u./hr. based on outdoor design temperature 95° (dry bulb) and 78° (wet bulb). On applying a heat lag factor through the structure, however, a net cooling load of 26,000 B.t.u./hr. was computed.

While the experimental house was somewhat less well insulated (i.e., had a higher than desirable heat factor) than structures in which heat-pump or electric-heat use would normally be recommended, nevertheless it showed electrical characteristics of use in an experimental type reflectively insulated farmhouse.

2/ Heat factor = $\dfrac{\text{kw.hr./degree day}}{\text{cu.ft./house volume in thousands}}$. Well-insulated houses will have a heat factor value varying between 0.2 and 0.3.

3/ By heat-pump-equipment manufacturers' representatives.

Figure I

Heat Pump Conditioned Farm Home

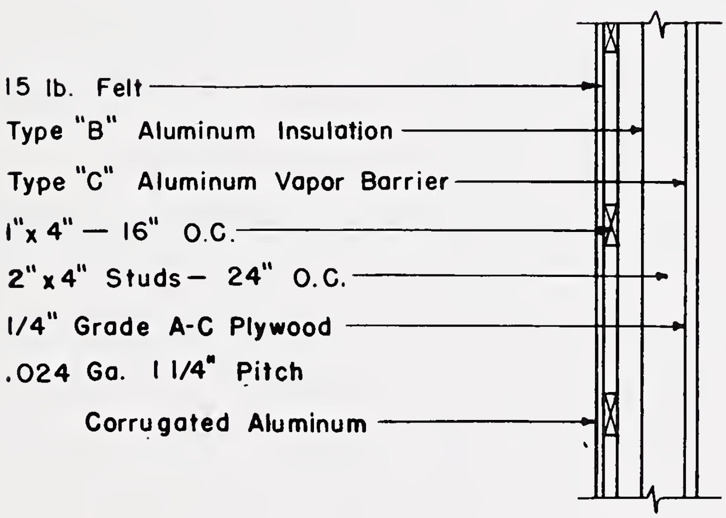
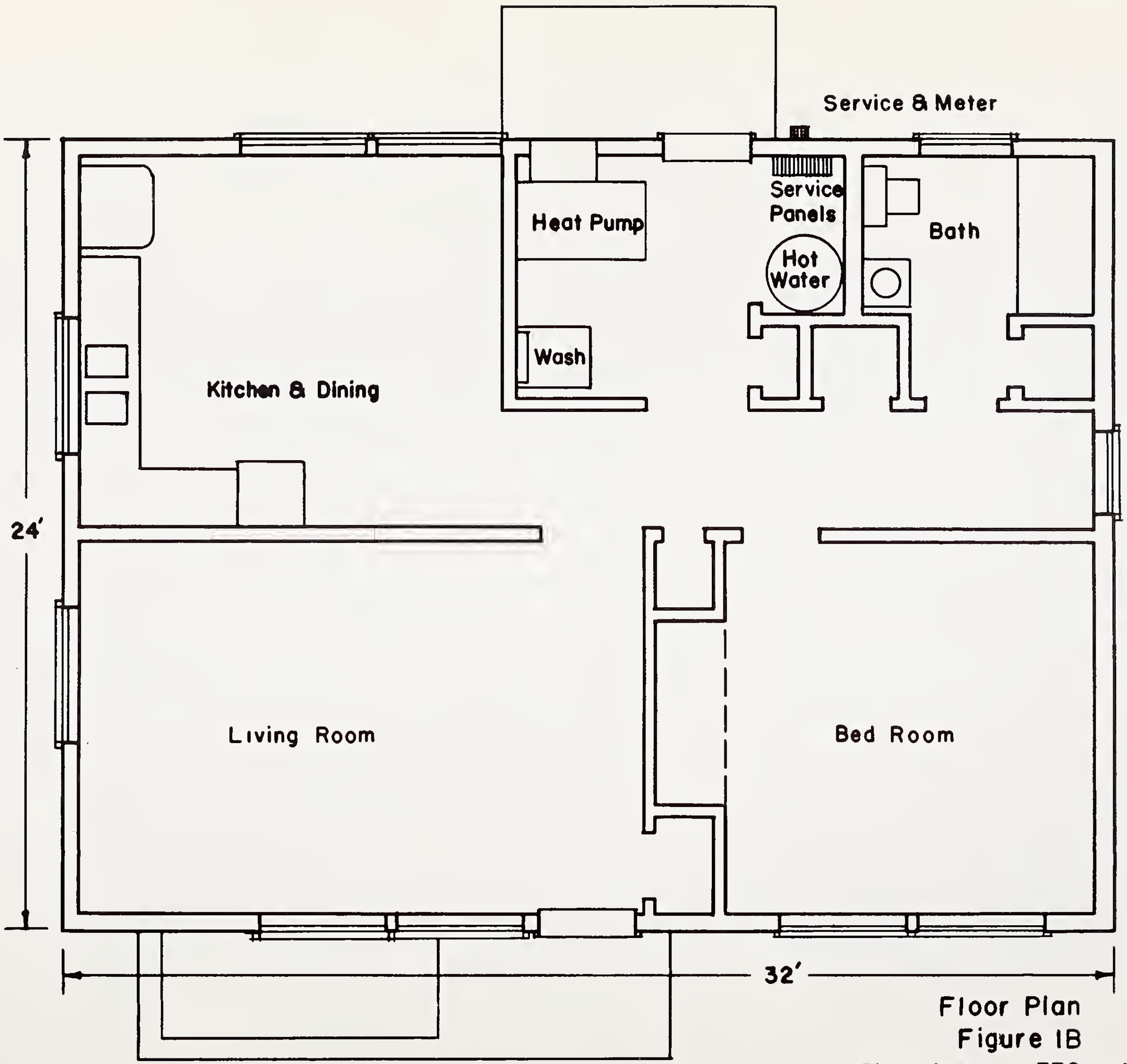


Figure I-A

Wall Section

Beltsville Experimental House "E"



Beltsville Experimental House "E"

Floor Plan
Figure 1B
Floor Area —— 770 sq. ft.
House Volume — 6750 cu. ft.

Heat-Pump Installation Description

A 3-hp. central heat pump with three steps, each of 2-kw. supplemental resistance heating, was installed in the utility room of the "built-on-slab" house. The steps of resistance heat were activated progressively[4/] by thermostats responding to decreasing outdoor temperatures.

The heat pump used, while of an early model, varied little in efficiency from present models. It had a 29,600 B.t.u./hr.[5/] cooling capacity and 25,800 to 37,500[6/] B.t.u./hr. heating capacity depending on air-source temperature. The 230-volt, single-phase unit had a 3-hp. compressor motor with 1/2-hp. outdoor and indoor fans.

Air-distribution ducts were insulated with 1-in. glass wool. A flexible canvas connection to the heat pump was used to prevent vibration and air-distribution noise. Hallway air returns proved satisfactory because of the type of construction.

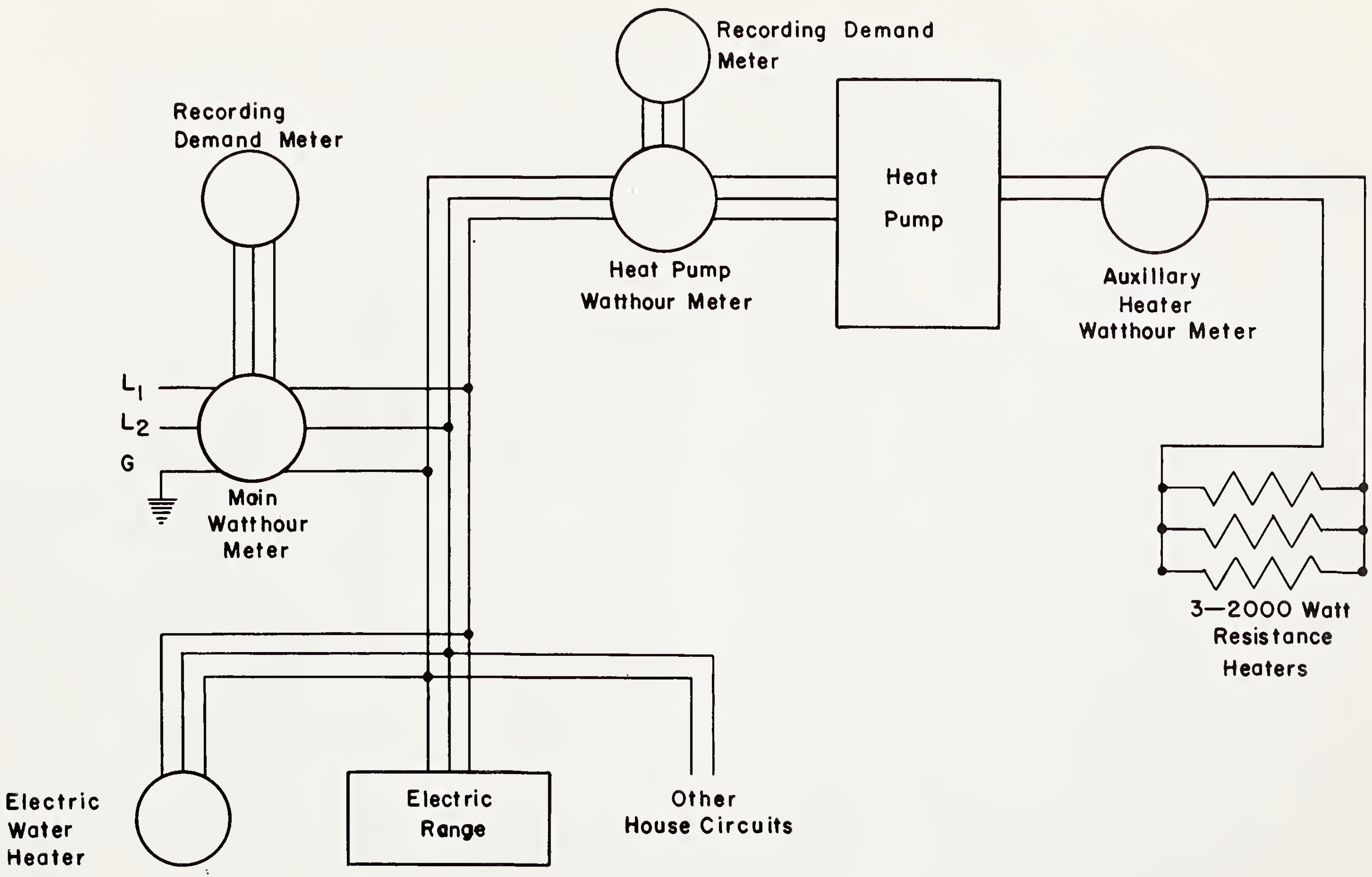
During the nearly 2 years preceding occupancy, the house was heated and cooled to make necessary adjustments and conduct some of the investigations of house heat loss and of heat-pump performance. This information would have been difficult to obtain when the house was in use.

Instrumentation

Electrical instrumentation (Fig. 2) included separate watt-hour meters with back-connected 30-minute demand recorders for the house and heat pump. An operational recorder was used to indicate whether equipment was operating on heating or cooling and to provide information on the number of activated stages of booster resistance heat. Other miscellaneous data, including wind velocity and number of door openings made for heat-loss estimations, were provided by the recorder.

A recording potentiometer, for recording outdoor and indoor globe thermometer and conventional thermocouple dry-bulb temperatures, was provided to obtain "on-the-site" weather data.

4/ Thermostat settings were 32°, 20°, and 15°F., respectively.
5/ At 80°F. (D.B.) and 67°(W.B.) air entering indoor coil and with an airflow of 2100 cfm. at 95°F. (D.B.) over the outdoor coil.
6/ At 20° and 45°F. Air entering outdoor coil.



Electrical Instrumentation and Connections

Figure 2

The kilowatt-hour and recording demand meters were supplied, calibrated, and corrected by the local power supplier on whose system the installation was made.[7/]

Experimental Procedure

Before occupancy of the house, precise heat-loss estimates were obtained in 1955, by using only the resistance heaters of the heat-pump unit.

Equipment coefficient of performance (heat output of equipment/equivalent heat-energy input) was estimated by measuring the quantity of air, its temperature rise through the heat-pump unit, and the quantity of electric energy required. When allowances were made for electric heat input by the motors, performance for heat was found to vary with outdoor temperature--approximately as the manufacturers' ratings indicated (Fig. 3).

During the following period, when the house was occupied, the electric demand of both the house and heat pump was recorded on charts which were changed weekly. The inhabitants preferred a winter temperature of 76° to 80° F., and they regulated the thermostat accordingly. This may have been due to the relatively large areas of glass and the less-than-desirable insulation causing radiant loss to such extent that the occupants compensated by higher thermostat settings. Operation in this temperature range would be expected to require more energy than operation at a more commonly used temperature setting.

Treatment of Data

The electric demand--as read from the charts--was averaged for 1/2-hour periods, consolidated into monthly summaries, and then plotted.

Totals thus obtained were compared with the corresponding kilowatt-hour meter readings to verify accuracy. Maximum demands were taken directly from these data, and these values were used in computation of monthly load factors (Table 1).

Results and Discussion

1. MONTHLY ENERGY CONSUMPTION AND LOAD FACTOR

Table 1 gives the recorded energy consumption for the 3-year period of test. Making allowance for the period when all-electric resistance

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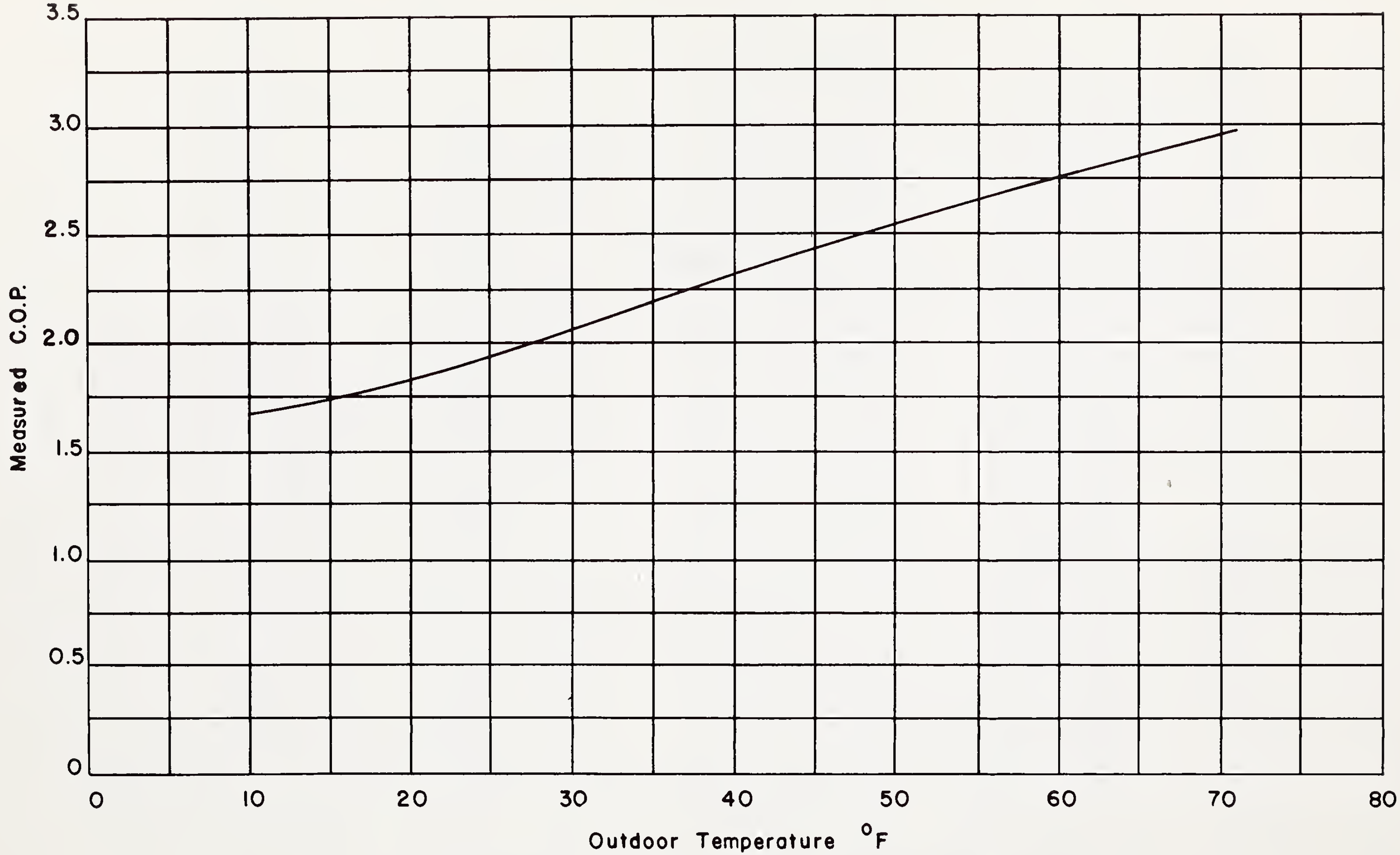
7/ Potomac Electric Power Company, Washington, D. C.



Heat Pump C.O.P. At Varying Outdoor Temperatures

Figure 3

Table I. -- Heat Pump Electric Energy Characteristics

	Maximum demand	Energy consumption	Monthly load factor	Degree days1/
1955	Kw.	Kw.-Hr.	%	
January	9.0	2/3,095	2/46.3	1,028
February	9.4	2/2,509	2/39.7	922
March	9.3	1,260	36.0	628
April	3.1	628	18.6	294
May	4.8	611	16.8	105
June	4.2	614	20.0	47
July	5.3	868	27.4	0
August	3.3	609	19.2	0
September	6.2	890	27.6	43
October	6.2	932	25.6	277
November	8.0	1,209	34.2	682
December	7.6	1,791	53.5	1,075
		Total---15,016	Avg.--30.4	Total---5,101
1956				
January	8.0	2,296	68.5	1,058
February	7.0	1,700	54.3	798
March	6.0	1,895	54.2	772
April	6.0	1,230	36.2	459
May	4.4	455	12.6	208
June	4.2	598	19.5	31
July	4.0	687	23.1	3
August	4.2	717	23.0	11
September	4.8	481	14.0	132
October	6.2	447	9.7	276
November	8.0	1,174	20.4	613
December	5.6	1,357	32.5	709
		Total---13,037	Avg.--30.7	Total---5,070
1957				
January	9.0	2,496	37.3	1,109
February	5.2	1,650	47.1	745
March	5.8	1,469	34.1	723
April	4.0	727	24.4	339
May	4.0	473	15.9	147
June	4.2	762	25.2	19
July	6.0	844	18.9	2
August	3.8	621	22.0	2
September	3.6	582	22.5	71
October	6.6	602	12.3	461
November	5.8	1,042	25.3	572
December	7.6	1,813	32.0	842
		Total---13,081	Avg.--26.4	Total---5,032

1/ Beltsville Station Weather Bureau Record.

2/ Direct electric heating during portions of the period for house heat loss calibration invalidates data for normal heat-pump operation.

heat was employed, the energy requirement varied between 13,037 and 13,081 kilowatt-hours each year.

The monthly load factors varied considerably, with relatively low values occurring during the fall and spring months. For this single installation, an average monthly load factor of 29.2 is an indication of the effect of the heat pump on the system load factor in the winter. The maximum demands for winter heating occur during the operating temperatures at which system equipment can be uprated above normal ratings. According to interested power suppliers, annual load factor of heat-pump installations based on the contribution to annual system peak demands will improve the annual system load factor, in distinction from many other loads encountered on rural distribution systems.

Diversified load with several heat pumps would further improve the system load factor.

2. HEAT-PUMP DEMAND--HEATING SEASON

Figure 4 represents the 30-minute-average heat-pump demand (Curve B) during January 1956, and its relation to that of the power system (Curve A). Similarly plotted data for the months of November through February indicated similar patterns.

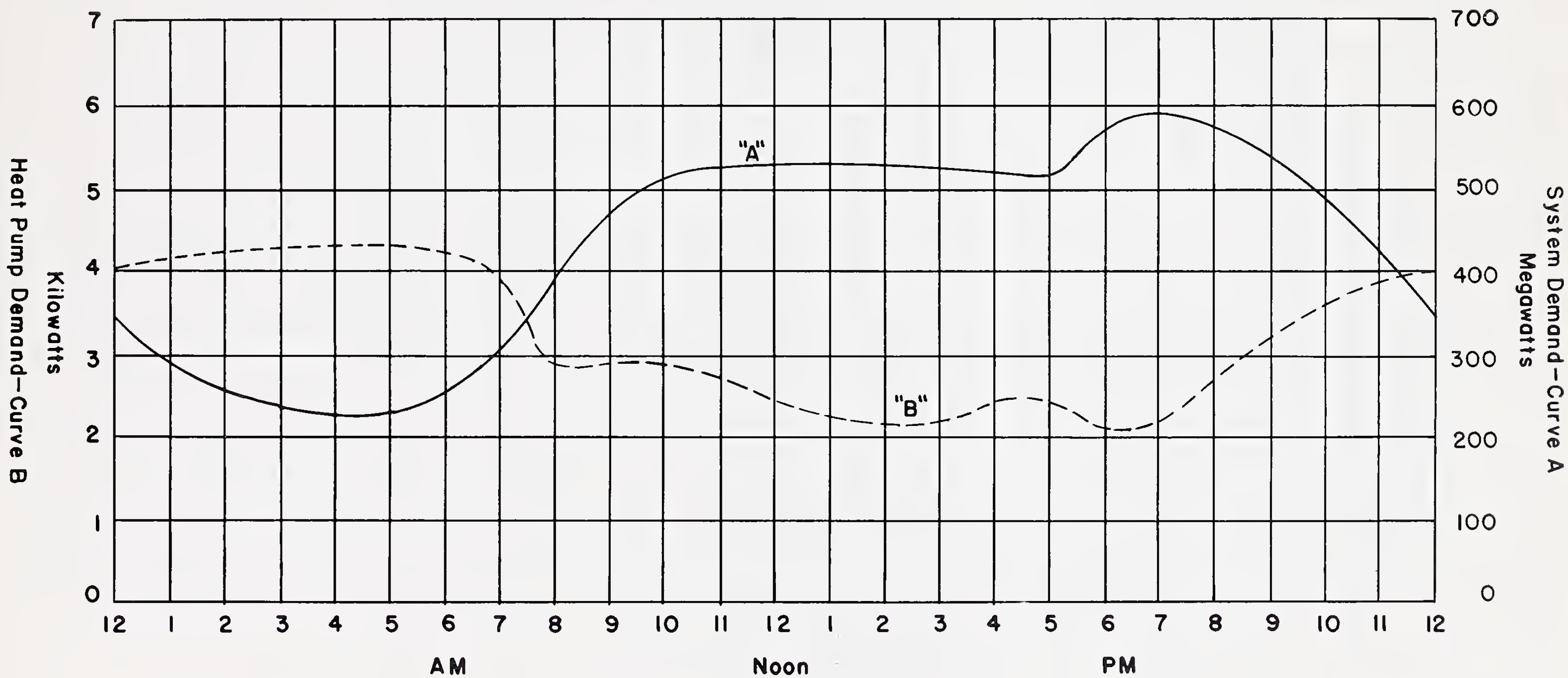
Lower energy consumption and demand occurred during the 8 a.m. to 8 p.m. period. The larger demands occurred during the late evening and early morning hours, thus fitting into the typical off-peak period experienced almost universally on electric systems, even though night setback to approximately 70° F. was practiced.

The maximum demands (Table 1), which included supplemental electric booster heaters with the heat pump, occurred without exception in the early morning hours during the heating seasons. The magnitude of this maximum demand is considerably lower than that which would have occurred with electrical resistance heating alone used to satisfy the required heating load, at extreme conditions encountered.

An extra demand charge to the heat-pump owner might thus either be avoided or substantially reduced in magnitude.

Figure 4

Relationship of System to 3-hp Air Source Heat Pump Electrical Demand
For The Month of January
1956



Hours Of The Day

Beltsville Experimental House "E"

3. HEAT-PUMP DEMAND--COOLING AND OTHER SEASONS

Contrary to the heat-pump demand for the heating season, average and maximum heat-pump electric demands during the cooling season--June, July, August--reached peak values during the 1 p.m. to 6 p.m. period, when system loads were also maximum (Fig. 5). Minimum heat-pump demand occurred during the early morning hours.

Summer operation of the heat pump was thus parallel to system requirements and showed the same general pattern exhibited by other types of air-conditioning equipment.

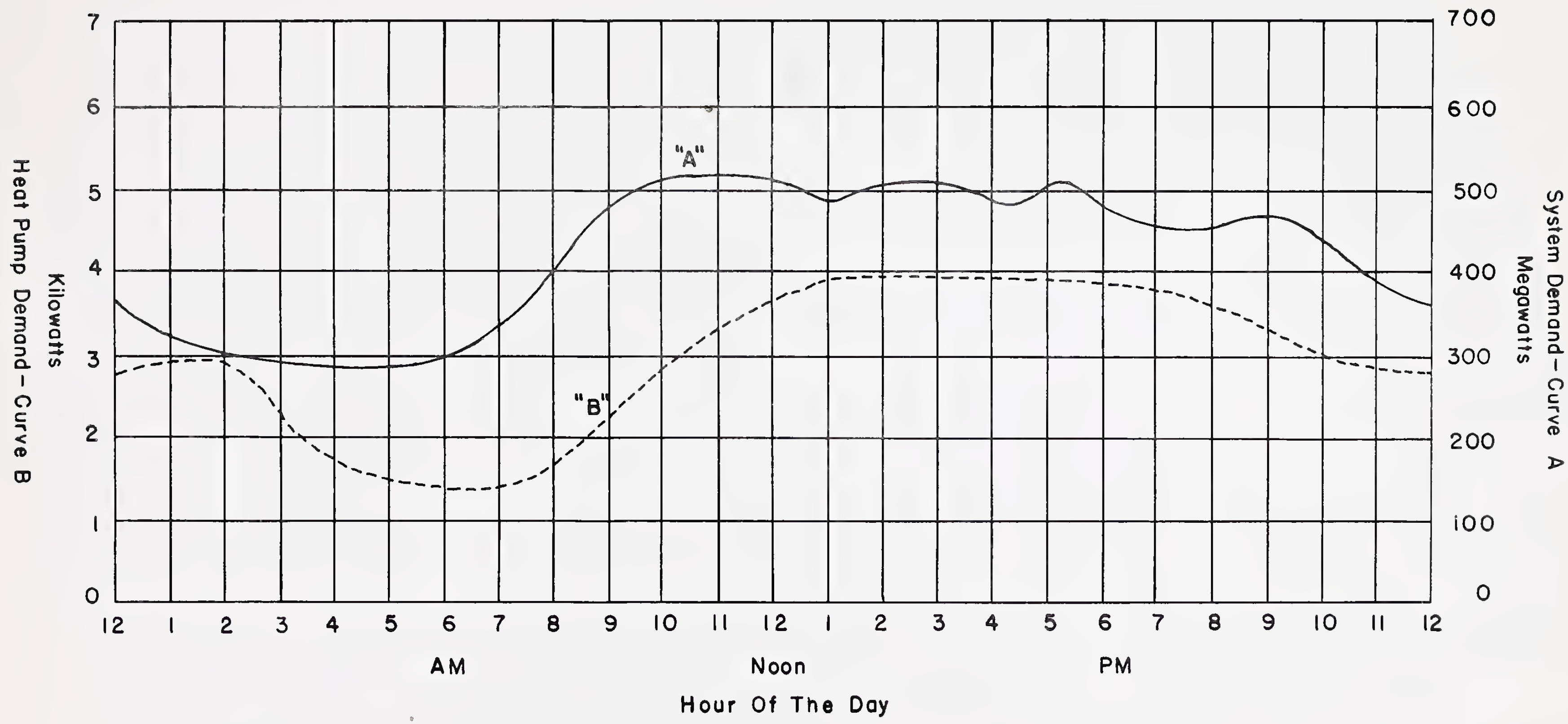
Fall and summer operation during the 3-year period indicated no significant demand pattern when compared to system demand. The variability of climatic conditions from day to day from year to year during these periods is primarily responsible for the lack of a clear pattern.

Summary

The heating season electric load provided by heat pumps can be readily seen as complementary to the system demand. This aids greatly in balancing the demand during the heating season on systems with summer peaks. The inference which may be drawn is that since this is true, the heat pump is a desirable additional load builder for many power suppliers where an imbalance between summer and winter systems exists. The better winter-summer-system balance achieved through use of the heat pump will thus result in convenient and economical, automatic year-round comfort air conditioning for the house-owner.

Figure 5

Relationship of System to 3-hp Air Source Heat Pump Electrical Demand
For The Month of July
1956



Beltsville Experimental House "E"